Project ID#: mat211

Sustainable Lightweight Intelligent Composites (SLIC) for Next-Generation Vehicles

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Newport Sensors, Inc.

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2022 DOE Vehicle Technologies Office Annual Merit Review

Overview

Timeline

- Start date: Aug 23, 2021
- End date: Aug 22, 2023
- Project complete: 30%

Budget

- DOE SBIR FY2021: $1.1M

Partners

- Subcontractor: University of North Texas
- Project Lead: Newport Sensors, Inc.

Barriers and Technical Targets

- High fiber cost and difficulty in damage inspection hinder wide deployment of lightweight CFRP composites for reducing vehicle GHG emission

  (Light-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials Workshop Report, February 2013)

Relevance

Impact

- Accelerate adoption of composites in automotive vehicles by addressing the most significant obstacles – the cost and the difficulty in damage detection.
- Lower weight by 50% of steel baseline. Lightweight vehicles incorporating sustainable natural fibers benefit environment.

Objectives

- Develop a highly innovative multifunctional composite that is embedded with two distributed sensor systems self-powered by vehicle vibration energy for in-situ self-health monitoring and real-time damage alerts.
- Enhance crashworthiness through hybridization of carbon fibers with natural fibers.

Milestones

Tasks	Status	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
T1: Design Multifunctional SLIC System	On schedule								
T2: Development of Self-Powered Dual-Sensing Self-SHM System	On schedule				1				
2-1: Conductive Trace Sensor	On schedule								
2-2: Piezoelectric PVDF Sensor	On schedule								
2-3: Energy Harvester	On schedule								
T3: Design and Prototype SLIC Specimens	On schedule						2		
T4: Experimental Evaluation of Structural and SHM Performance	On schedule								
4-1: Tensile Test	Complete								
4-2: Bending Test	On schedule								
4-3: Impact Test	-								
T5: Design, Prototype, Test, and Demonstrate a SLIC Bumper Beam	-								3

Today

Milestones:
1. By **Q4**, the self-powered dual-sensing self-SHM system will complete.
2. By **Q6**, the structural and SHM functionalities will be validated.
3. By **Q8**, the SLIC bumper beam will be demonstrated.

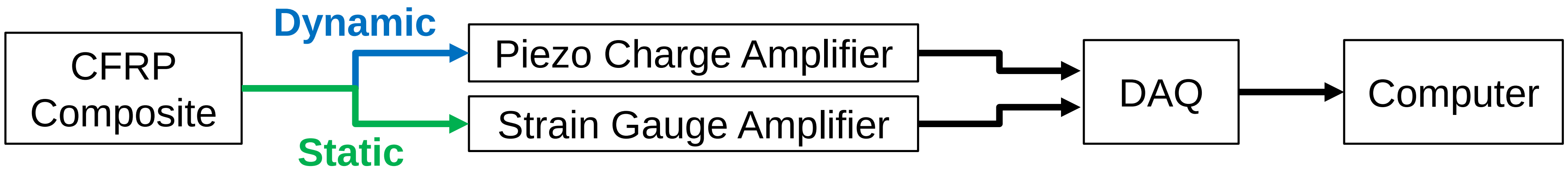
Approach

Design Multifunctional Composite

- Embedded with two types of sensors:
  - Dynamic – Piezoelectric PVDF film for impact loads and damage
  - Static – Conductive trace sensor for strain monitoring
- Hybridized carbon-natural fiber for improved crashworthiness and reduced weight and cost

Develop Dual-Sensing System Integrated with Structural Material

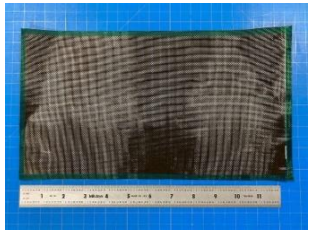
- Integrate the circuits of two types of sensors (dynamic and static) into one system
- A streamlined design to save sensor material cost



Accomplishments: Specimen and Sensing System

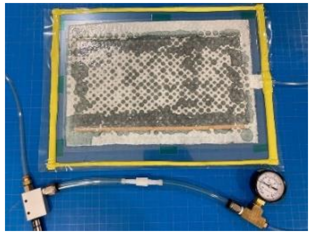
Specimen Fabrication for Tensile Test

- Specimen is created with carbon fiber shell and natural fiber core by vacuum bagging method
- Composite panel is sliced and tabbed according to tensile test ASTM D3039
- Copper coated PVDF film is etched to create strain gauge pattern and attached on carbon fiber surface

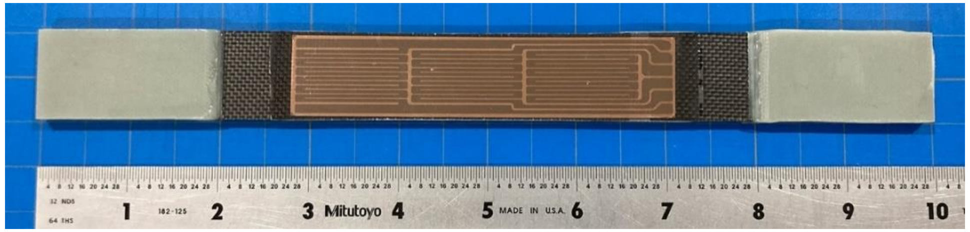


Carbon Fiber

Natural Fiber Core



Vacuum Bagging



Fabricated Specimen

Multi-Sectional Simultaneous Piezoelectric and Strain Sensing System

- Developed piezo and strain amplifiers that can simultaneously measure piezo electric charge and strain at multiple sections on specimen

Accomplishments: Tensile Test

Test Setup

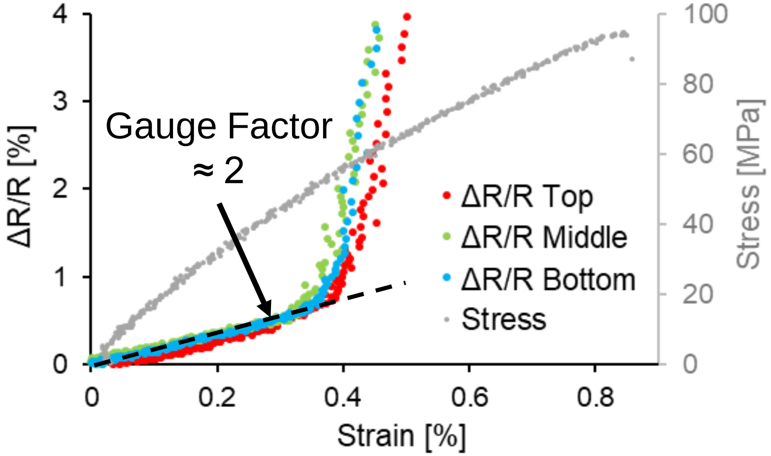
- Tensile test with universal testing machine
- Strain measurement with camera using digital image correlation

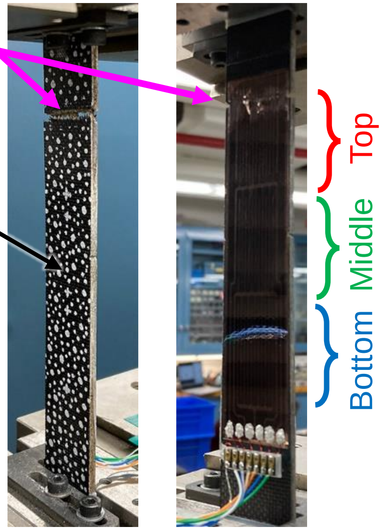
Test Result

- Conductive trace sensor measured strain up to 0.4% with gauge factor ≈ 2
- PVDF film detected initialization of micro cracks and identified their location 20 seconds before failure

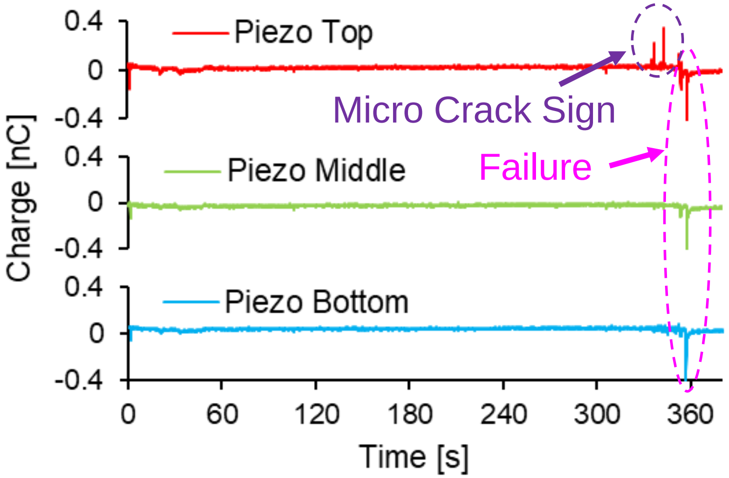
- Successfully measured strain;
- Successfully detected micro cracks and identified their locations, demonstrating efficacy for early warning of composite failure

Universal Testing Machine





Specimen After Failure



Responses to Previous Year Reviewers' Comments

"The impact or other damage sensing needs to be demonstrated using an automotive CFRP to be relevant or, alternatively, the sensing technology could be pursued as a coating or thin layer to be applied to automotive composites to track impact. In that case, it does not need to be composed of CF itself, as CF on the vehicle is for mechanical reinforcement, not for use as electrodes."

- We modified our approach for PVDF film to be applied on the CFRP surface for easier integration into automotive parts
- We still use the CF as the electrode for the purpose of signal ground which should not have any obstacle

"It was not clear to the reviewer if the sensing is a damage detection or an impact detection. The reviewer asked about how the signals differ between an impact without causing damage and an impact with damage. Also, it is not clear if the capacitor circuit and the high pass filter circuit are embedded in the composite structure or they are separate from the composite."

- The piezoelectric sensor can detect initiation of microcracks of the composites.
- We added conductive trace sensor for strain measurement and surface crack detection which further enhances the damage detection functionality.
- All circuits will be separated from the composite

Collaboration

University of North Texas (Sub)
(Prof. Sheldon Shi)

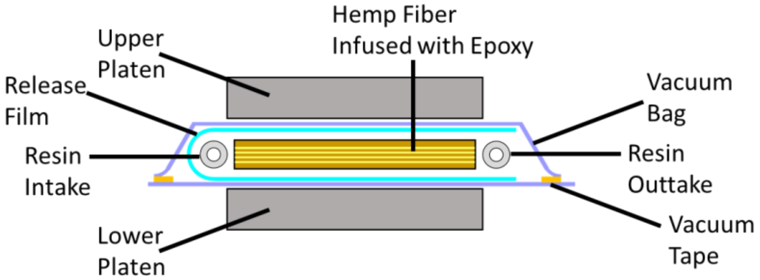
- Hemp/Epoxy Composite Panel Fabrication
- Tensile Test: ASTM D3039
- Bending Test: ASTM D7264
- Impact Test: ASTM D6110

Hemp Fiber Mat

Wabash Genesis Hydraulic Hot Press

Shimadzu AGSX

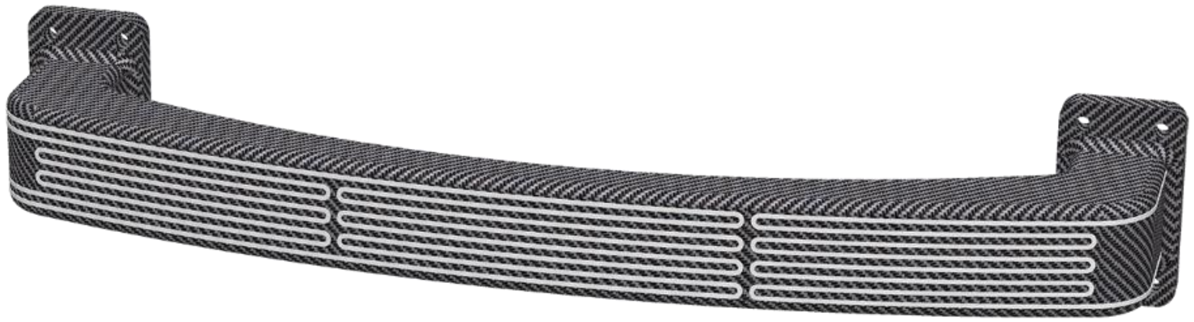
AMETEK Impact Testing Machine



Vacuum Assisted Resin Infusion (VARI) with Pressing

Proposed Future Research

- Combine energy-harvesting function studied in Phase I with developed dual-sensing system (Piezoelectric/Conductive trace sensor)
- Conduct remaining coupon tests (bending and impact) to determine the composite mechanical properties to compare to baseline material such as plain CFRP
- Design and fabricate miniature size bumper beam using multifunctional composites



Sustainable Lightweight Intelligent Composites (SLIC) Bumper Beam

Any proposed future work is subject to change based on funding levels

Summary

- Successfully created a multifunctional carbon/natural fiber reinforced polymer composite specimen as a vehicle structural material that can be doubled as a distributed piezoelectric and conductive trace strain sensor
- Developed a novel dual-sensing system for simultaneous measurement of Piezoelectric charge and conductive trace strain
- Tensile testing of the specimen demonstrated that
  - conductive trace sensor worked as a strain gauge for strain monitoring,
  - disconnection of conductive trace sensor detected the damage,
  - PVDF Piezoelectric sensor detected micro cracks prior to composite failure, demonstrating its efficacy for early warning
  - multi-sectional sensor design enabled damage location capability